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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 420

Contribution from the Bureau of Animal Industry
A. D. MELVIN, Chief

Washington, D. C. PROFESSIONAL PAPER **October 27, 1916**

COOLING HOT-BOTTLED PASTEURIZED MILK BY FORCED AIR

By

S. HENRY AYERS, JOHN T. BOWEN, and
W. T. JOHNSON, Jr., Dairy Division

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INTRODUCTION.

Since 1912 the process of cooling hot bottled milk by means of forced-air draft has been studied in the Dairy Division of the Bureau of Animal Industry. The first experiments, which were conducted on a laboratory scale, indicated that forced-air circulation might be successfully used for cooling hot pasteurized milk in bottles. The results of that investigation [1] indicate the probable means by which the method could be used on a commercial scale. It was realized that laboratory and commercial conditions are essentially different, and in consequence cooling experiments on a 30-crate basis were started in 1913. In this paper we shall give the results of this work. As additional information, some data on the reverse process—the heating of cold bottled milk by means of circulated hot air—will also be given.

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[1] Ayers, S. Henry, and Johnson, W. T., jr., Pasteurizing Milk in Bottles and Bottling Hot Milk Pasteurized in Bulk. Bulletin 240, U. S. Department of Agriculture. Also in Jour. of Infec. Dis., vol. 14, No. 2, March, 1914, pp. 217-241.

DESCRIPTION OF EXPERIMENTAL APPARATUS.

In order to conduct cooling experiments with forced-air circulation on a small scale, an insulated box 10 feet 6 inches high, 5 feet wide, and 4 feet 8½ inches deep was constructed. The box was insulated by a 4-inch wall of sawdust, and inside it was built a platform 2 feet 2 inches from the floor, composed of movable sections each the size of the bottom of a milk-bottle crate. The plan of this box, together with the blower set and arrangement of piping, is shown in figure 1.

The blower set consisted of a steel-blade fan of a capacity of 2,000 cubic feet a minute at normal speed, and was operated by a 125-volt direct-current, shunt-wound, open-type, variable-speed motor of 1½ horsepower. The blower was connected to the box by pipes of galvanized iron of 14-inch diameter, which were so arranged that air could be forced in at the bottom of the box and out at the top, or the reverse; that is, in at the top and out at the bottom. This was made possible by two inlet and outlet pipes connected with the box and controlled by a system of dampers.

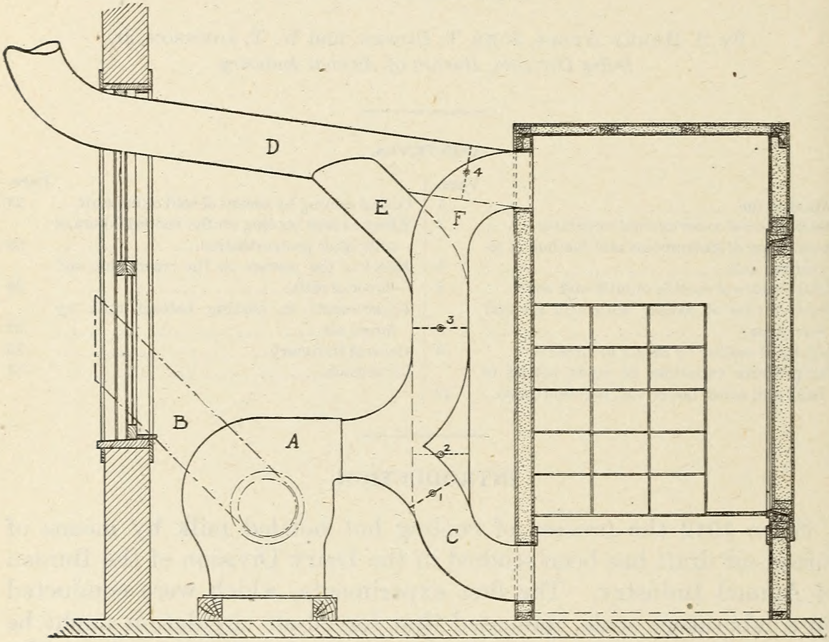

FIG. 1.—General arrangement of cooling apparatus.

Most of our experiments were conducted during the winter months; consequently the outside air was sufficiently cold for the cooling process. As may be seen in the figure, the blower drew outside air through pipe B and forced it into the cooling box.

Thirty crates of bottles, stacked in six piles each five crates high inside the box, were cooled at one time. Before the crates were stacked on the platform the movable sections were removed, so that the space under the crates was open and the rest of the platform closed. By this arrangement it was possible to force all the air directly through the crates of bottles.

When air was forced up through the crates the operation was as follows: Air was drawn by blower A through pipe B from the outside of the building and forced through pipe C into the bottom of the cooling box. From that point it was forced up through the piles of crates and passed out from the top through pipe D. In this case damper No. 1 in pipe C was open and damper No. 3 in pipe F was closed, while damper No. 2 in pipe E was closed and damper No. 4 in pipe D was open.

When air was to be forced down through the crates, and consequently had to enter at the top of the box, it was necessary simply to change the dampers in the pipes. To force air in at the top through pipe E, damper No. 1 was closed and No. 3 opened; in the outlet pipes damper No. 2 was opened and No. 4 closed. This system of pipes and dampers would not be necessary for cooling milk on a commercial scale, but was necessary for experimental purposes.

DESCRIPTION OF INSTRUMENTS AND METHOD OF RECORDING DATA.

Temperatures [1] were determined with copper-constantin thermo elements made from No. 30 wire, tested to the required degree of accuracy for thermoelectric homogeneity. Junctions were soldered, wound with silk thread, and inclosed in thin glass tubes. Where leads were exposed to steam or air blast the double-silk insulation was protected by being incased in black-rubber tubing. Each element was composed of two pairs of couples in series. A calibration curve for each element was constructed from the potential given when the cold junction was immersed in a thermos bottle containing crushed ice, and the hot junction was immersed (1) in melting ice, (2) in a fusion of recrystallized sodium sulphate (Richard's point), and (3) in steam at known barometric pressure. In each case the temperature was also taken with a thermometer calibrated by the Bureau of Standards. From the calibrations so obtained deviation curves were constructed and used with Adams's [2] table.

Potentials were measured with a Leeds and Northrup potentiometer and galvanometer. The potentiometer was calibrated by the Bureau of Standards. A Weston cell certified by that bureau furnished the known potential. A switch, essentially the same as that described by White,[1] was used to correct for parasitic electromotive forces.

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[1] We are greatly indebted to Dr. W. M. Clark, of the Dairy Division, for preparing, describing, and operating a system for temperature measurements by means of thermocouples.

[2] Adams, L. H. Journal of American Chemical Society, 36, p. 65, 1914.

In the set-up the hot junction of each element was placed where desired and the cold one packed in crushed ice within a thermos bottle. The terminals were led to mercury pools in a block of paraffined wood protected from air currents. Connection with the potentiometer was made through copper leads whose bared and amalgamated ends could be dipped in the successive pairs of mercury pools. In this way any element could be quickly and easily brought into circuit.

Differences of one microvolt could be detected by the system. This corresponds to approximately 0.018° F. (0.01° C.). The experimental errors incident to rapid readings resulted in an accuracy of about 0.09° F. (0.05° C.).

In determining the difference in temperature between the top and bottom of a bottle a differential thermo element was used; this consisted of two pairs of copper-constantin couples in a thin glass tube. The hot and cold junctions were placed so that one would be about one-half inch above the bottom and the other just beneath the surface of the liquid when cool. This differential couple was not calibrated, and its design was not all that could be desired, but it doubtless was sufficiently accurate to furnish a fairly good measure of the differences in temperature between the top and bottom layers. In this connection it may be noted that the thermometers used in this work are numbered from 1 to 10, which numbers are used to identify them with the curves in the drawings showing the results of the various experiments.

Air measurements were taken with a Taylor-Pitot tube placed in the center of the straight part of the discharge pipe from the box, about 4 feet from the nearest bend. The tube was arranged to give both the impact and static pressure, their difference, or the velocity head, being indicated on a graduated water column. Only one tube, situated in the center of the pipe, was used. The average velocity head across the entire section of the pipe was determined by multiplying this center reading by the factor 0.91.

The velocities obtained with the Pitot tube were checked with an anemometer which had been calibrated by the Bureau of Standards. The anemometer was moved across the end of the outlet pipe in such a way as to give what was considered an average reading. As the temperature of the air in the outlet pipe from the box was, of course, higher than that of the incoming air, the volumes were corrected in the ratio of their absolute temperatures to give the inlet volume.

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[1] White, Walter P. Journal of American Chemical Society, 36, p. 1856, 1914.

The corrected anemometer readings were in every case higher by approximately 10 per cent than those obtained with the Pitot tube.

The wet-bulb and the dry-bulb temperatures were taken by a sling psychrometer. The barometer was read during each test, and the weight of air per cubic foot determined from the barometer and the wet-bulb and the dry-bulb readings.

Readings of air velocities were also taken with an anemometer over the tops of the crates. These readings, taken at different places over the stacks, were practically the same and averaged 182 feet a minute over the quart crates and 156 over the pints. It is very important that a practically uniform velocity of air be maintained throughout the stack in order to cool all bottles at the same rate. Thirty crates, stacked 5 high, were used in all experiments, 15 for quart bottles and 15 for pints. Reading of volts, amperes, and speed of motor were also taken during each experiment.

RELATIVE RATE OF COOLING OF MILK AND WATER.

As the average specific heat of whole milk is less than that of water, it may be expected to cool faster under the same conditions. This, however, is not the case when the cooling is done in bulk, such as when in bottles or cans, as is plainly shown in figure 2. These curves are plotted from temperature readings taken in a quart bottle of milk and a quart bottle of water, subjected to the same conditions of air velocity, air temperature, location of thermometers in bottles, etc.

It will be seen that the curve representing the rate of cooling the milk is of a uniformly higher temperature than the similar curve for water.

On account of the small variation in the relative rate of the cooling of milk and water it was considered advisable to use water in these experiments, as it was more easily obtained and handled. Bottles of milk, however, were distributed throughout the crates, in selected places, and in these bottles, as well as in those containing water, similarly placed, the temperature readings were taken.

RELATIVE RATE OF COOLING WITH STILL AIR AND FORCED AIR.

In order to obtain data to compare the rate of cooling bottles and cans containing milk when exposed to still air and to moving air, pint and quart bottles, and 10-gallon cans of milk were placed in a refrigerated room, the constant temperature of which was held at approximately 40° F. (4.4° C.). The initial temperature of the milk was about the same in all instances. The results are seen in figures 3, 4, and 5. Figures 3 and 4 show the relative drop in temperature between pints and quarts, respectively, when exposed to still air and to moving air, and figure 5 shows similar results for the 10-gallon cans.

The bottles placed in still air were cooled by natural circulation brought about by the difference in temperature between the comparatively warm air in contact with the outer surface of the bottles and that at a distance. As the air in contact with a hot surface, such as that of the bottles containing milk, becomes heated, it rises and its place is taken by cold air; hence, the rate of circulation of the air depends upon the difference in weight of the respective columns of warm and cold air. As this difference in weight is very slight, the circulation is naturally slow, and hence a slow rate of cooling follows.

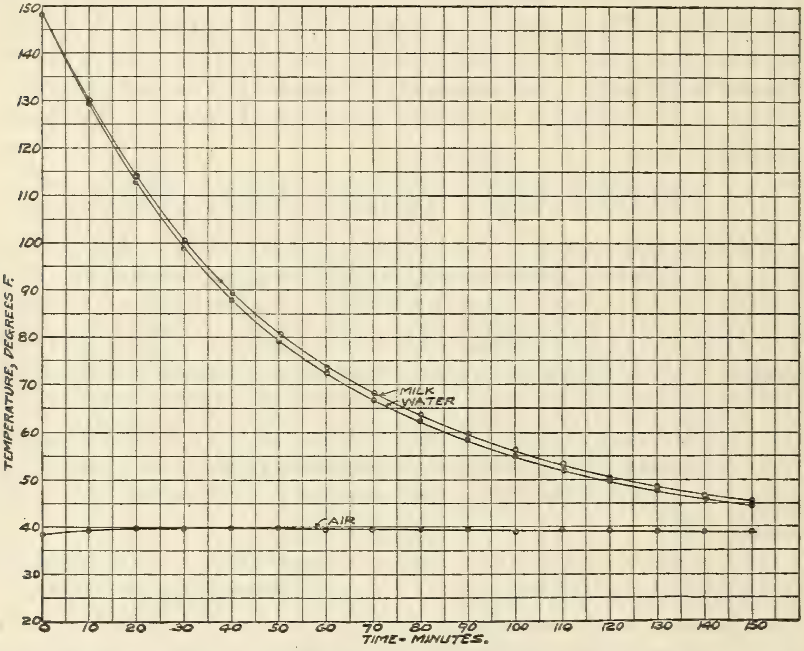

FIG. 2.—Cooling of milk and water by forced air.—Difference in the rate of cooling of milk and water when exposed to an air blast. Quart bottles.

In the case of forced circulation of air, however, the film or sleeve of hot air surrounding the vessel is broken up, and a large volume of cold air is brought into direct contact with the outer surface of the container; the cooling therefore goes on very much faster. The forced circulation of the air in these experiments was made by a 16-inch electric fan, which produced over the bottles an air velocity of approximately 1,250 feet a minute, measured by an anemometer which had just been calibrated by the Bureau of Standards.

It will be noted by reference to figure 3 that it required 4½ hours to reduce the temperature of the milk in the pint bottles when placed in still air from 142° to 50° F. (61.1° to 10° C.) with a practically constant temperature of 40° F. (4.4° C.) inside the room. When the air was circulated, however, this drop in temperature was obtained in 1 hour and 27 minutes, or in approximately one-third the time required for an equal drop in temperature when the bottles were exposed to still air.

Referring to the two similar curves in figure 4, showing the results obtained with quart bottles of milk under the same conditions, it will be noted that the relative rate of cooling between the bottles exposed to still air and moving air is the same as that for pint bottles, except that the quart bottles are uniformly higher in temperature than the pints for the same period of cooling.

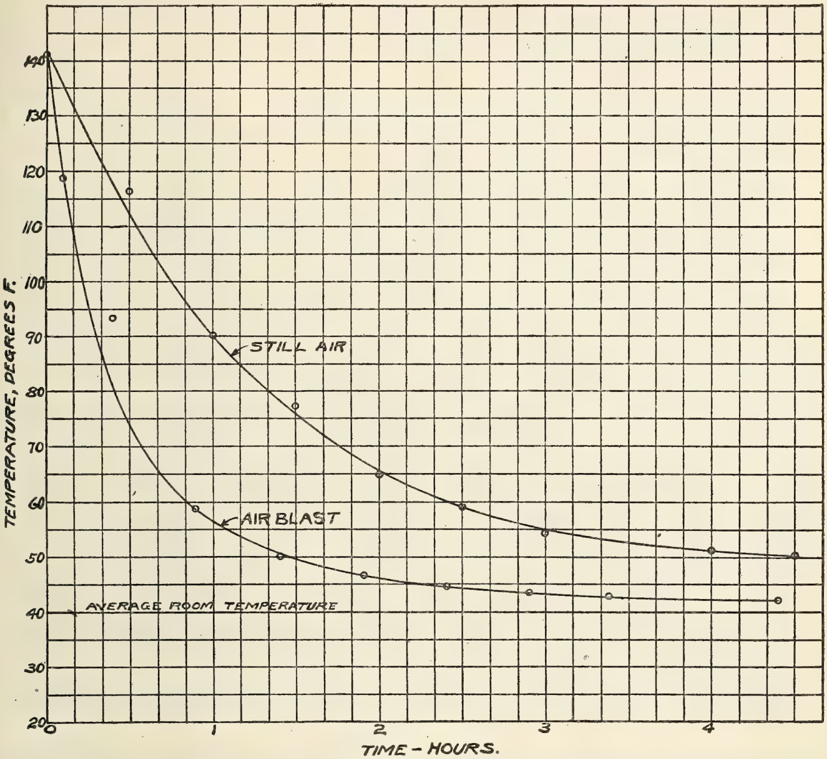

FIG. 3.—Cooling in still air compared with forced air.—Relative drop in temperature between pint bottles of milk cooled in still and moving air. Velocity of moving air 1,250 feet per minute.

The curves in figure 5 show the relative drop in temperature of the milk contained in 10-gallon cans when placed in still air and in moving air. The air blast in this case was also furnished by a 16-inch electric fan which gave an air velocity of 1,250 feet a minute. The conditions were practically the same as those for the pints and quarts, except that the temperature inside the room averaged 42° F. (5.5° C.), or 2 degrees higher. The temperature of the milk contained in the 10-gallon can, placed in still air, was reduced to only

90° F. (32.2° C.) in 6½ hours. A corresponding drop in temperature, however, was obtained with moving air in 2 hours and 15 minutes. The relative rate of cooling between the milk contained in the two cans was in the ratio of about 1 to 3, or, the milk contained in the can which was subjected to an air blast required only about one-third the time to drop in temperature from 147° to 90° F. (63.9° to 32.2° C.) as did the can placed in still air.

Under the foregoing conditions the relative rate of cooling, then, seems to be about the same in vessels of equal size and shape. The time required, however, for cooling through a given range, other things being equal, depends on the size of the containing vessel. In fact, it is believed that in commercial practice quart bottles are about the limiting size of containers that should be used. Our experiments with forced-air cooling, therefore, deal only with pint and quart bottles of hot milk or water.

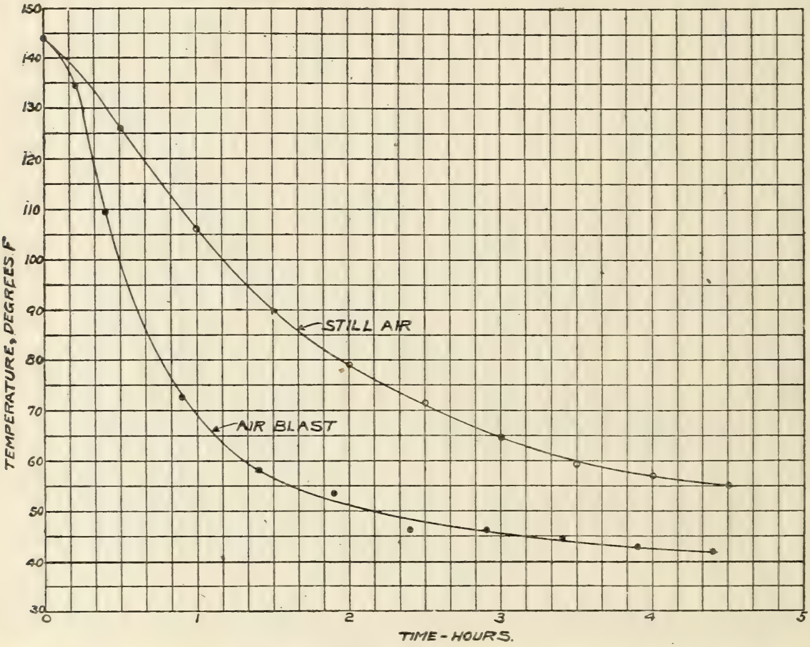

FIG. 4.—Cooling in still air compared with forced air.—Relative drop in temperature between quart bottles of milk cooled in still and moving air. Velocity of moving air 1,250 feet per minute.

In the foregoing experiments with moving air the air was forced in a horizontal direction over the containers. The direction of the air flow, when cooling milk by forced circulation, affects materially the rate of cooling and also the variation in temperatures of bottles at different points in the stack. This feature will be discussed later.

The foregoing experiments serve principally to show that the time required to cool milk to any great extent by natural circulation is too slow for satisfactory operation on a commercial scale, and that with forced-air circulation it is necessary to have small containers, such as quart or pint bottles. In these experiments only a few bottles were cooled by natural circulation; if a large number had been stacked in piles the cooling process would have been even slower.

RESULTS OF COOLING BY MEANS OF FORCED AIR.

BY FORCING THE AIR FROM BOTTOM UPWARD.

The experiments previously described were of a preliminary nature, and we shall now take up the cooling experiments performed on a 30-crate basis.

The cooling effect of cold air when forced through stacks of crates from the bottom is shown by the curves in figures 6 to 9, inclusive.

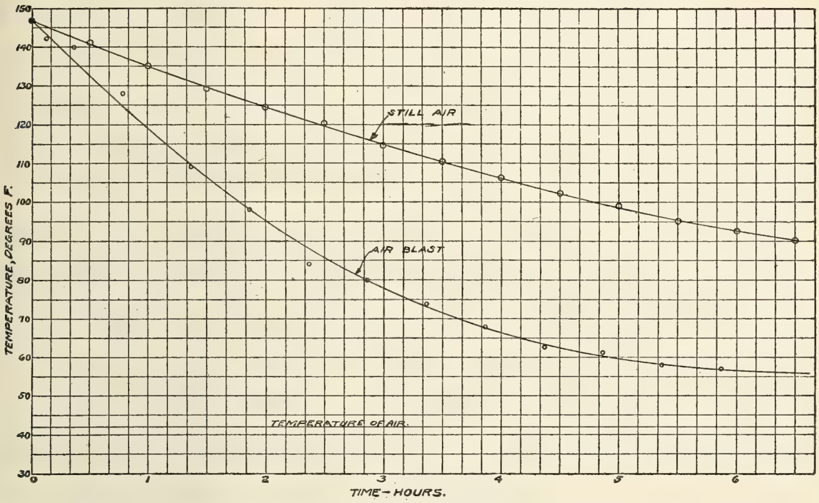

FIG. 5.—Cooling in still air compared with forced air.—Relative rate of cooling of 10-gallon cans of milk when placed in still and in moving air. Velocity of moving air 1,250 feet per minue.

The results, shown graphically by the curves, have been selected on account of some special feature, the discussion of which follows immediately after each set of curves.

All the experiments made with air entering at the bottom and flowing upward and around the bottles show a wide difference in temperature between pint and quart bottles occupying upper and lower positions in the stack, this temperature varying with the height of the particular bottle from the bottom of the stack. The lower bottles, over which the cold air first passed, of course cooled faster than the upper ones, and the rate of cooling decreased rapidly as the distance from the cold-air inlet increased. The temperatures were very accurately determined by means of thermocouples, which have already been described. Several experiments were carried out, using air at different temperatures for cooling purposes.

In figure 6 are shown the results of cooling by air at an average temperature of 67.9° F. (19.9° C.). A complete set of curves is incorporated, principally to show the rate of cooling with air at this high initial temperature. Curves 3 and 4 show the relative rate of cooling between quart bottles of milk and water, respectively, when placed side by side at the bottom of the stack. These curves agree very closely with those in figure 2. Curves 5 and 6 show, respectively, the rate of cooling between pints and quarts placed at the top, or fifth, tier of crates. Curves 3 and 6 are plotted from temperature readings taken in the lower quart of milk and the upper quart of water, respectively. The average difference in temperature between these bottles was 9.8° F. (5.4° C.), while the maximum difference was about 19° F. (10.5° C.). Curves 5 and 6 are practically parallel throughout the range, the curve showing the drop in temperature of the pint remaining throughout about 5 degrees lower than that of the quart. The average difference in temperature between curves 4 and 6, which are plotted from temperature readings taken in the lower and upper quarts of water, respectively, is 10.5° F. (5.8° C.), while the greatest is 20° F. (11.1° C.).

The temperatures indicated by the curves in figure 7 were determined in a pint and a quart bottle at the top of the stack and also one of each kind at the bottom. The temperature of the lower quart and pint, as shown by curves 3 and 4, respectively, drops below that of the outgoing air. It should be remembered, however, that the temperature of the outgoing air was taken at the point where it left the box; hence, the temperature of the air passing over the bottles was lower than that indicated by the curves. Toward the end of the run the temperature of the lower pint was reduced below that of the incoming air. This was caused by the temperature of the outside air rising so rapidly that that of the lower pint, which had been cooled, had not had sufficient time to adjust itself to the rising temperature of the outside air. The average difference between the lower pint and the upper quart, curves 4 and 5, was about 25° F. (13.9° C.), while the maximum difference in temperature was about 43° F. (23.9° C.). This difference becomes more marked when the temperature of the outside air is lower, consequently, when blowing air up through the crates there is great danger of the top crates not being cooled properly, while on the other hand the milk in the lower crates may be frozen, provided the initial temperature of the incoming air is below the freezing point. By comparing temperature curves 3 and 6, lower quart and upper pint, respectively, it will be noted that the temperatures in the two bottles were much nearer each other. The maximum difference was about 12° F. (6.7° C.), but the average was

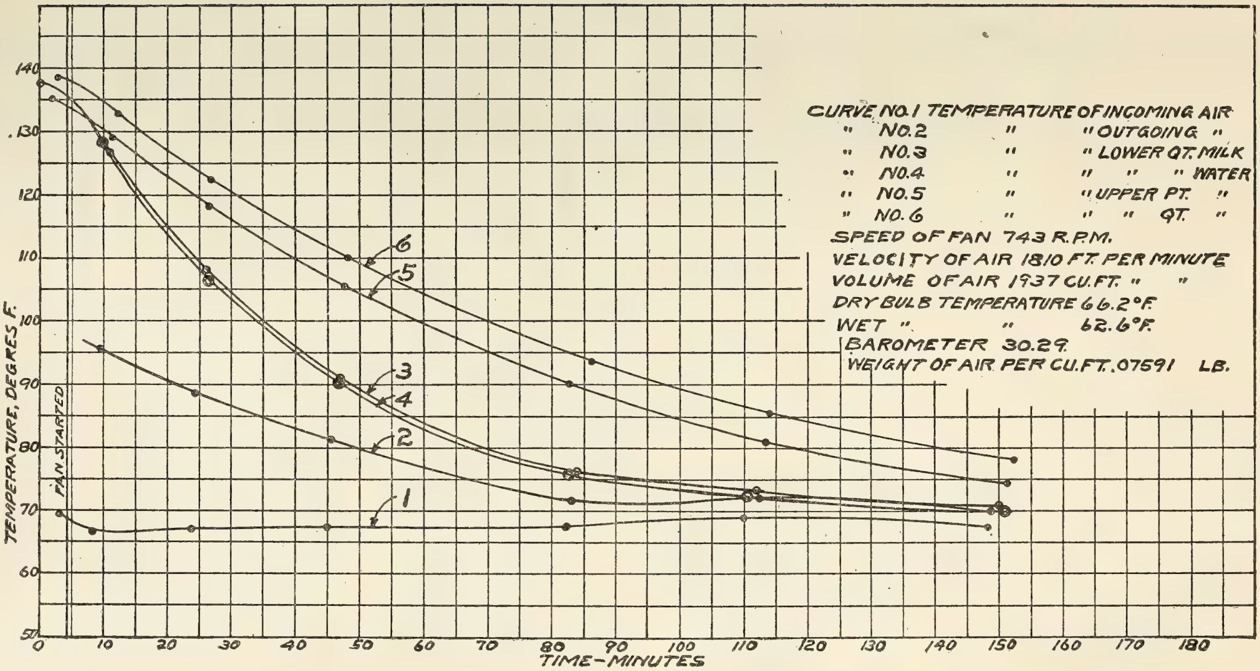

FIG. 6.—Cooling by forced air from bottom upward.—Relative drop in temperature of bottles of milk and water at different positions in stack.

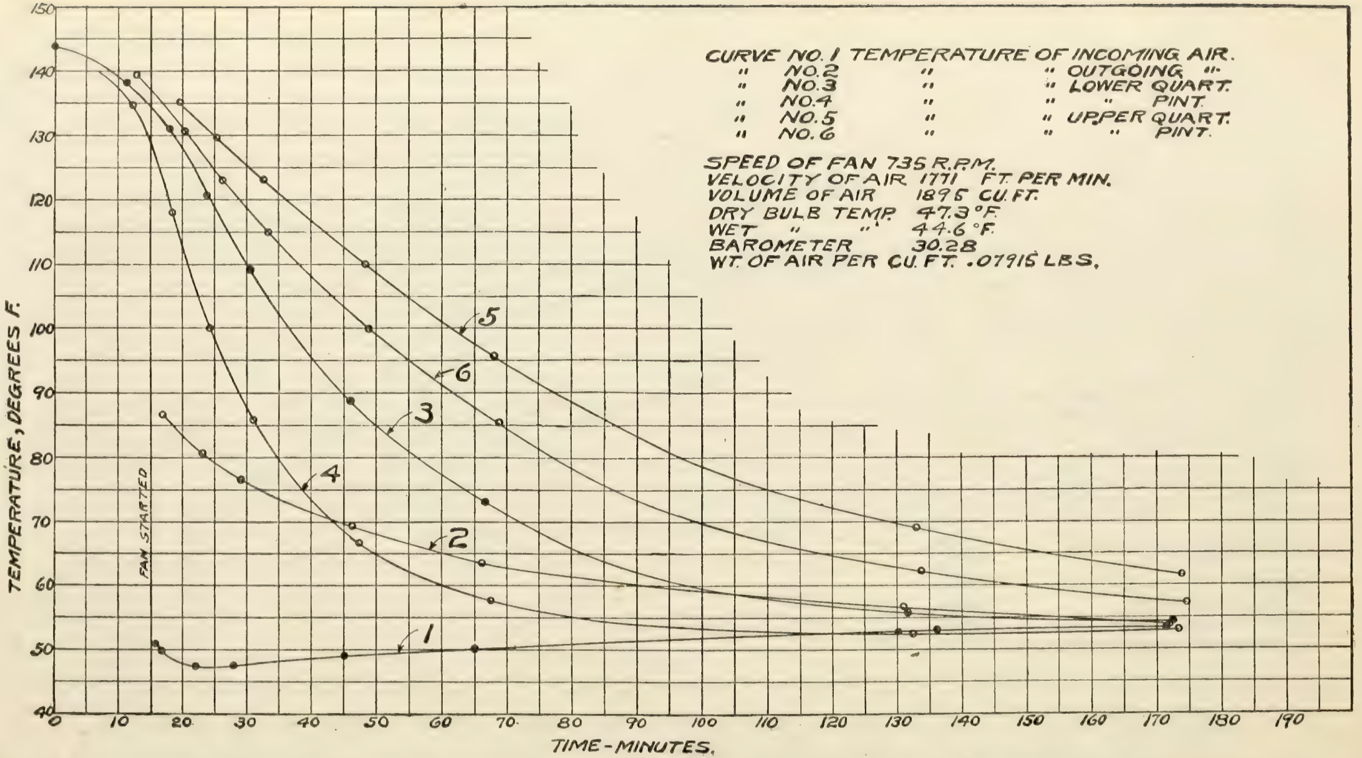

FIG. 7.—Cooling by forced air from bottom upward.—Difference in temperature between top and bottom bottles and incoming and outgoing air. Air in at bottom and out at top.

only about 5° F. (2.8° C.). Therefore, if the crates containing pint bottles were stacked on top of those containing the quarts, the temperature throughout the stack could be equalized to a certain extent. This would require, however, extra care and trouble in stacking.

The curves in figure 8 are plotted from temperatures taken in quart bottles in the first, third, fourth, and fifth tiers of crates, the bottles selected having been immediately above one another and in line. On account of not having a thermocouple available, the temperature in the second tier was not taken. Curves 3, 4, 5, and 6 show the difference in temperature of bottles in respect to one another when placed one above the other. It will be noted that the difference in temperature of adjacent bottles decreases rapidly as the distance from the bottom increases and also that there is a wide difference in the temperature of the top and bottom quarts.

The curves 3, 4, 5, and 6, in figure 9, showing the drop in temperature of pints and quarts, are nearer one another than those in figures 6, 7, and 8. This is owing to the initial temperature of the pint bottles being about 13° F. (7.2° C.) lower than that of the quarts. It is of course impracticable to adjust the initial temperatures of different-sized bottles so that the cooling will be more nearly uniform throughout the stack, and these curves are simply included as a matter of general information.

When the cold air is forced in at the bottom of the stack and up through the crates, the variation in temperature in different-sized bottles and the same-sized bottles at different positions in the stack is too great for satisfactory operation, and we do not believe this method would be commercially practicable. Consequently in our next experiments the direction of the air through the stack was reversed periodically, the cold air being blown through from the bottom for 15 minutes and then through from the top for the same period.

BY FORCING THE AIR ALTERNATELY FROM BOTTOM AND TOP.

The series of curves shown in figure 10 shows the effect of reversing the direction of air through the stacks. The air was forced through the stack from the bottom for 15 minutes, then reversed and forced through from the top for the same length of time. This arrangement was tried with the view of bringing the temperature of the top and bottom bottles nearer together. It may be noticed that the numbers on the curves in figure 10 do not correspond to those in the previous figures. As before stated, these numbers refer to the thermometers used in the work, and in the present case thermometers 1 and 2 recorded the temperature of the incoming air—one for the upward flow, the other for the downward flow. Nos. 8 and 9 recorded the outgoing air in a similar way.

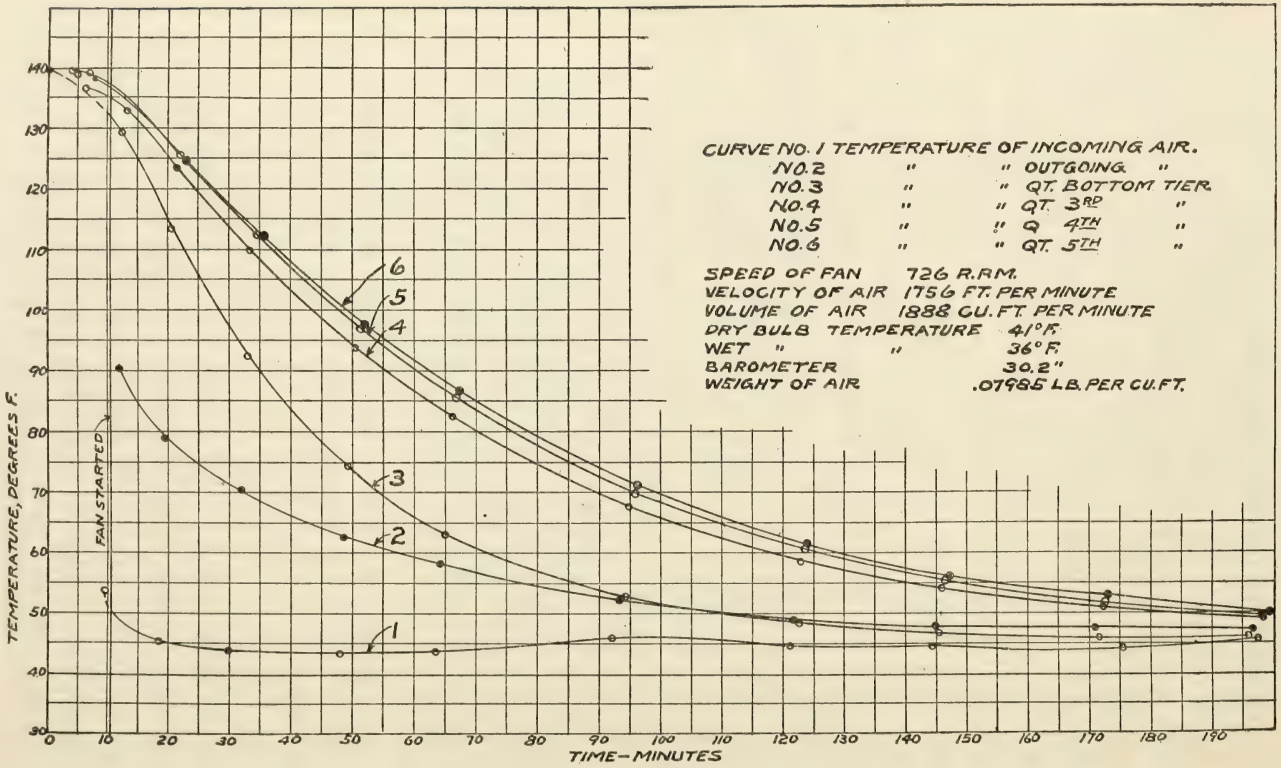

FIG. 8.—Cooling by forcing air from bottom upward.—Relative drop in temperature in bottles at different positions in stack.

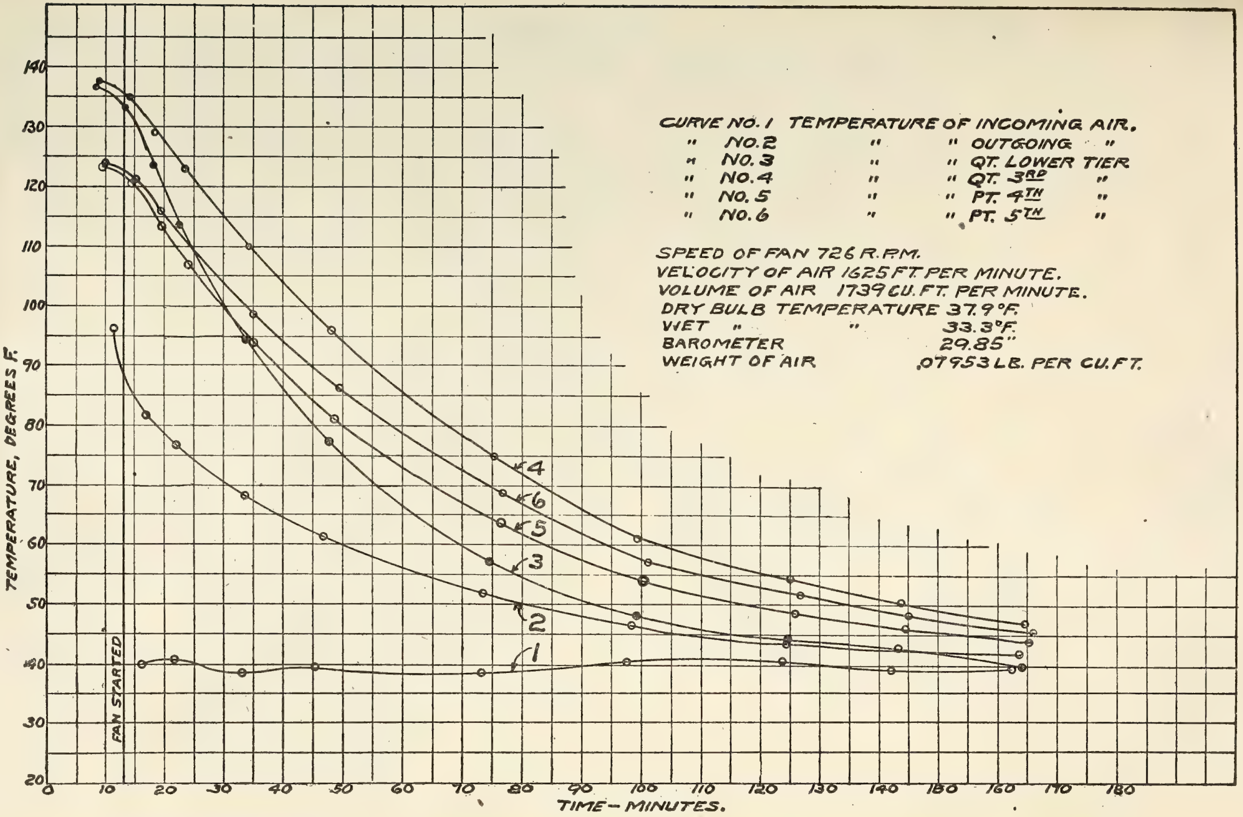

FIG. 9.—Cooling by forcing air from bottom upward.—Relative drop in temperature in bottles at different positions in stack.

While the difference in temperature between the top and bottom bottles was decreased to a certain extent by reversing the air, still there was too great a difference for satisfactory operation commercially, as there is a possibility that some of the bottles are not properly cooled. Furthermore, the arrangement of piping, in order to provide for the reversal of the direction of the air through the crates, was more or less complicated and would involve an increased cost in the installation of the dampers so as to change the direction of the air for cooling on a commercial scale.

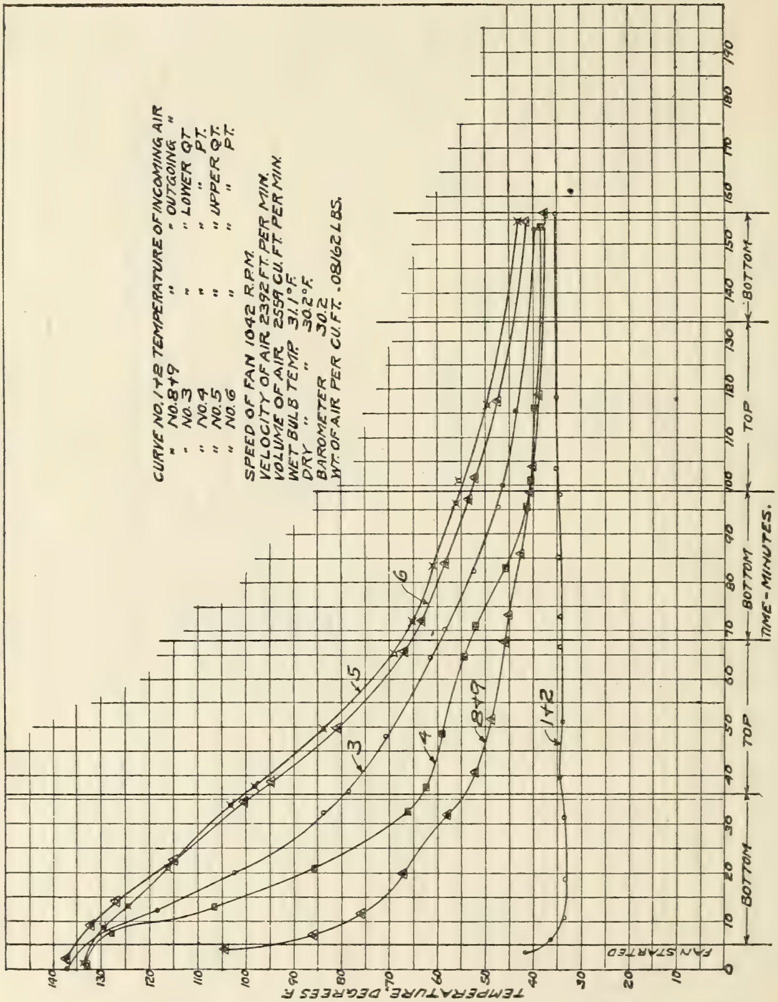

FIG. 10.—Cooling by forcing air alternately from bottom and top.—Difference in temperature of bottles at different positions in stack. Air reversed in direction every 15 minutes.

BY FORCING THE AIR FROM THE TOP DOWNWARD.

As it is natural to expect, the results obtained by admitting the air at the top of the box, forcing it downward through the stacks of crates, and out near the bottom of the box, show that it is by far the best method. With this arrangement the liquid in the upper part of the bottles is cooled first, and of course, owing to its greater density, settles to the bottom of the bottles, allowing the warmer and therefore lighter liquid to rise to the top and take its place. The convection currents are thus taken advantage of, with the result that the extreme difference in temperature between the lower quarts and the upper pints is only a few degrees. In view of this fact the possibility of some of the bottles being insufficiently cooled, while others in extreme cases may be frozen, is remote when this arrangement is used. Furthermore, the rate of cooling was found to be considerably increased by this method as compared with the other two methods. In addition to giving a more nearly uniform temperature throughout the stack, the variation in the temperature of different parts of the same bottle was more nearly the same when the air was forced downward than when blown upward.

From the temperature curves in figure 11 it will be noted that the incoming air is at an average temperature of 40° F. (4.4° C.), and that with an air velocity of 2,512 feet a minute the time required to reduce the temperature of the lower quart to 50° F. (10° C.) was 2 hours and 10 minutes. The average difference in temperature between the lower quart and the upper pint was only 8.9° F. (4.9° C.). In this experiment, as in others, there was some variation in the initial temperature of the liquid before cooling was commenced. In this case the variation amounted to 8° to 10° F. (4.4° to 5.6° C.).

The curves in figure 12 show more plainly the results of cooling by blowing air downward through the stack than those in figure 11, for in the former case the initial temperature of all bottles is practically the same. The average difference in temperature between the lower quart and upper pint (curves 3 and 4, respectively, figure 12), representing extreme conditions both as to size and location of bottles, was only 2.49° F. (1.4° C.), while the maximum difference in temperature between these bottles was only 4.5° F. (2.5° C.). There was a difference of only 2° F. (1.1° C.) between the average and the maximum, showing that the cooling throughout the stack was practically uniform and that with this method all danger that some of the bottles are not thoroughly cooled is eliminated. If the temperature is taken in any one bottle it is safe to assume that the temperatures of the others are within a few degrees of the one taken when the crates are arranged as in the experiment. The average temperature of the incoming air was about 30° F. (−1.1° C.), and the contents of the bottles were cooled to about 50° F. (10° C.) in from 1 hour and 25 minutes to 1 hour and 35 minutes.

The results obtained with inlet air at approximately 20° F. (–6.7° C.) are shown by the curves in figure 13. In this experiment the bottles were cooled to 50° F. (10° C.) in approximately 1 hour and 20 minutes. Generally speaking, with lower temperatures of the inlet air the rate of cooling increases rapidly.

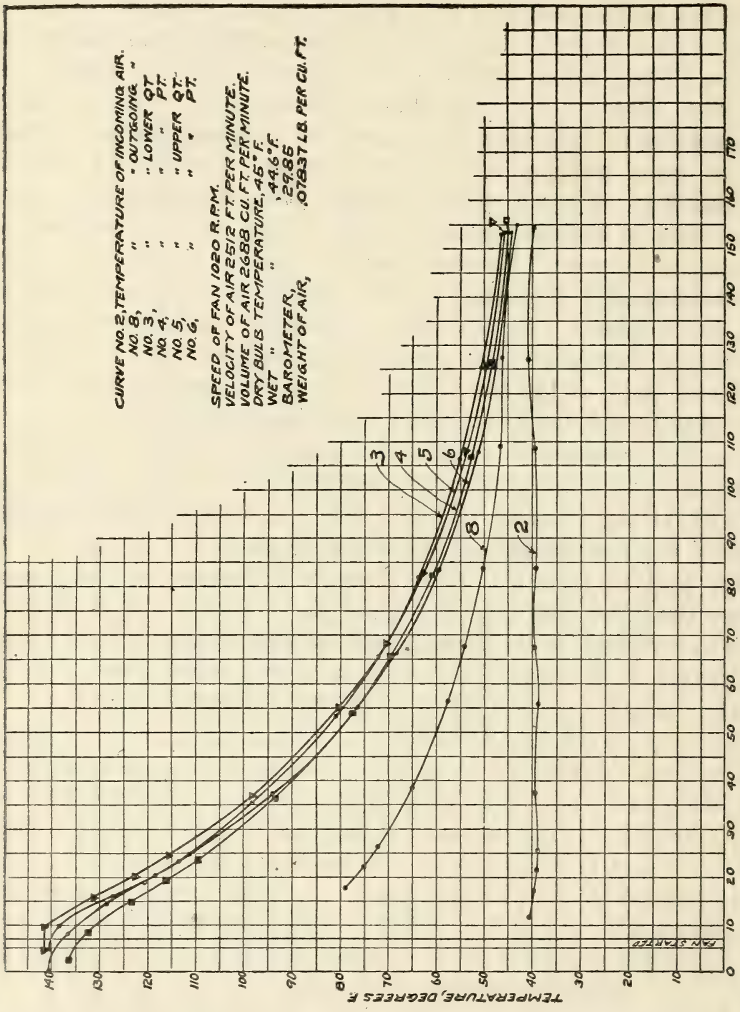

FIG. 11.—Cooling by forcing air from top downward.—Difference in temperature of bottles at different positions in stack.

A study of the curves which indicate the relative drop in temperature of bottles under different conditions and locations when air is blown through the stack from the bottom and from the top will show the advantages of the latter over the former.

TEMPERATURE VARIATIONS IN QUART BOTTLES OF MILK AND WATER UNDER VARYING CONDITIONS.

A differential thermocouple was placed in a quart bottle of milk, another in one of water, and the difference in temperature at the top and bottom of the bottles noted under varying air conditions and directions of flow. One of the junctions of the differential couple was placed about one-half inch above the bottom while the other was placed in the top just beneath the surface of the liquid when the latter was cooled, both being in the center line of the bottle.

The curve in figure 14 shows graphically the difference in temperature between the top and bottom of a quart bottle of milk when cooled by an air blast from the bottom of the stack. The average temperature of the cold-air supply was 39.4° F. (4.1° C.), and the velocity at which the air was blown up through the stack was 1,625 feet a minute. When the fan was started there was a difference of about 8° F. (4.4° C.) in temperature between the top and bottom of the bottle; 22 minutes later the difference had increased to about 23° F. (12.8° C.). Upon standing for a few minutes the bottom layers of milk will naturally be the colder, and with the same source of cold applied to the bottom of the bottle the difference in temperature will of course be increased, owing to the absence of convection currents in the milk itself. The rapidity with which the cooling goes on tends

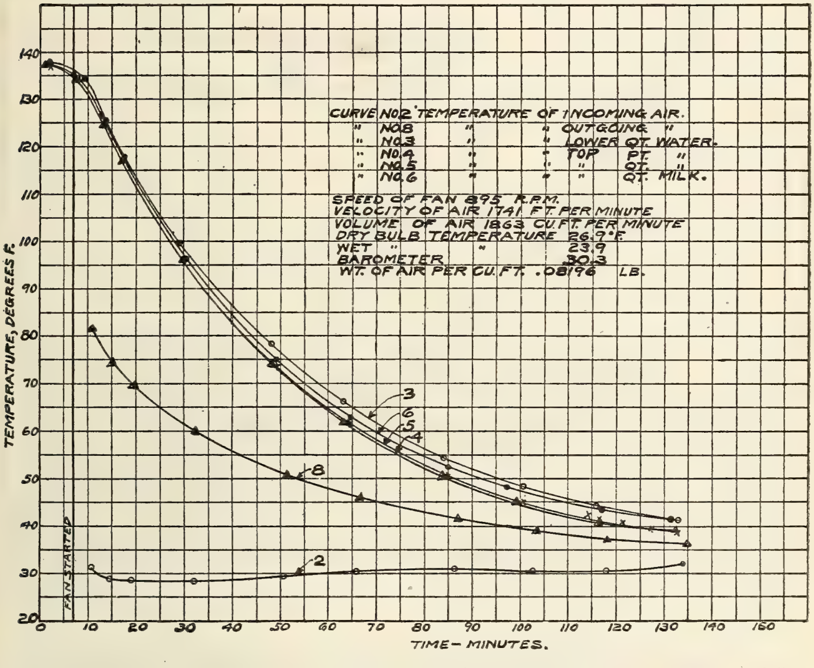

FIG. 12.—Cooling by forcing air from top downward.—Difference in temperature of bottles at different positions in stack.

to vary the difference in temperature between the top and bottom layers; the faster the cooling the greater the difference, and vice versa.

In addition to the wide variation in temperature between the top and bottom layers of milk when cooled by cold-air blast from the bottom of the stack, the whole time required to cool a given quantity is greater than if cooled by admitting the cold air at the top. This point is more fully discussed elsewhere, the principal cause being that when a liquid is cooled in volume the cooling is carried on principally by the convection current set up in the liquid itself and to a lesser extent by conduction.

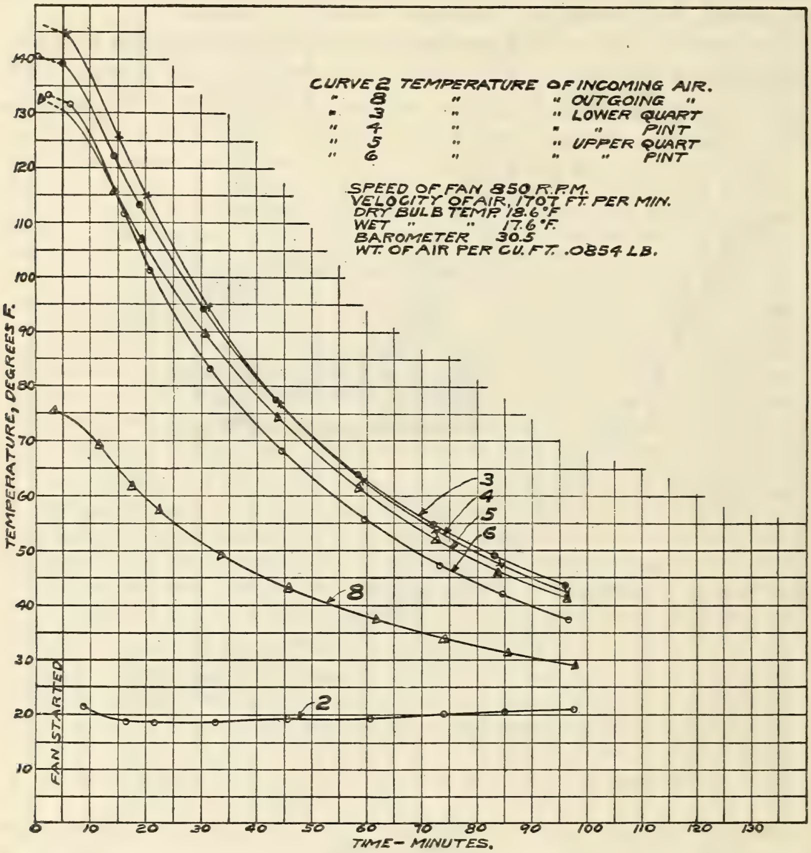

FIG. 13.—Cooling by forcing air from top downward.—Relative drop in temperature of bottles of milk at different positions in stack.

The results obtained by reversing the direction of the air through the stack are now given. The curve in figure 15 shows the results obtained by blowing cold air downward through the stack of crates. The supply of cold air was at an average initial temperature of 39.6° F. (4.2° C.), and the air velocity was 2,512 feet a minute. The air conditions in the two experiments were practically the same, except that the velocity of air in the latter case was considerably greater than in the former.

This experiment was repeated several times under different conditions, but the same general form of curve was obtained each time. Just after the fan supplying the cold air was started the difference in temperature between the top and bottom layers of milk was increased by a degree or two, after which it gradually fell. This slight increase just after starting was probably caused by a quick cooling of the bottom layer which remained at the bottom on account of its greater density, while the top layer gradually fell, its place being taken by a warm layer. These results show the advantage of cooling by blowing air downward through the crates.

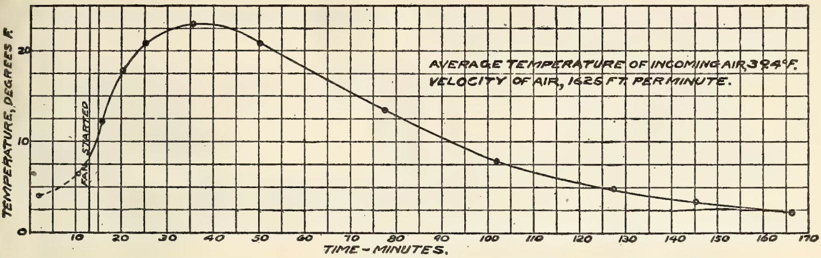

FIG. 14.—Variation in top and bottom of same bottle.—Difference in temperature between top and bottom of quart bottle of milk when cooled by air blown upward through stack.

The curves in figure 16 show the results obtained when either milk or water was cooled by cold air blown downward through the stack, the average temperature of the incoming air being 19.8° F. (– 7.7° C.) and the velocity of air 1,707 feet a minute. It will be seen in the figure that curves 2 and 8 show the variation in temperature of the incoming and outgoing air, while curves 5 and 6 show the drop in temperature of a quart bottle of milk and one of water, respectively. Curve 7 shows the difference in temperature between the top and bottom layers of milk, and curve 10 shows similar temperature differences taken in a quart of water. The solid line marked "0" is intended to represent the point where there is no difference in temperature between the top and bottom layers and is drawn on the temperature scale at 39.1° F. (3.9° C.), representing the maximum density of water. Readings below the zero line as a matter of convenience are considered as minus, and those above as plus. Curve 10, representing the action of water, is not so difficult of interpretation, but on the

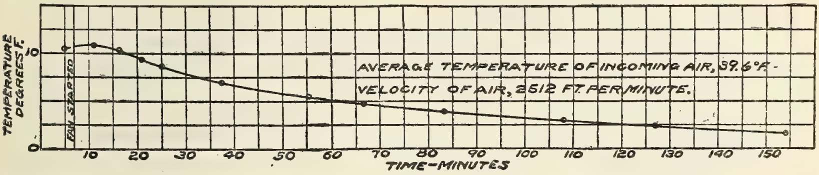

FIG. 15.—Variation in top and bottom of same bottle.—Difference in temperature between top and bottom of quart bottle of milk when cooled by air blown downward through stack.

other hand the action of the milk as represented by curve 7 is very difficult, owing to complications produced by the physical properties of milk under changing temperature conditions.

In curve 10 it will be noted that there was an increase in the difference in temperature between the top and bottom layers of the water just after the fan was started. This may be explained by the fact that there was an air space between the top of the liquid and the paper-cap covering which acted as a heat insulator, protecting the top layer of the water from the direct effect of the cold air, while the bottom layer, which was in direct contact with the bottom of the bottle, was chilled quickly, increasing the difference in the temperature between the top and bottom layers. The upper terminal of the differential couple was placed in the center of the neck of the bottle; hence with the air space in the bottle neck the top layer of the water was cooled to a great extent by conduction from the sides. There

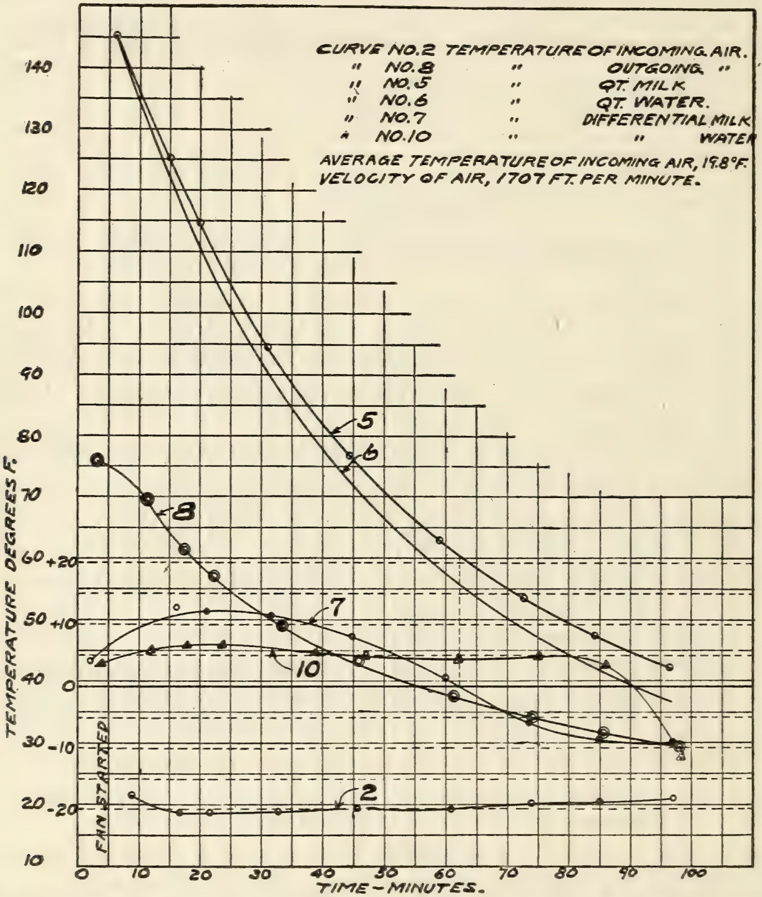

FIG. 16.—Relative drop in temperature of quart bottles of milk and water and incoming and outgoing air; also difference in temperature between top and bottom of quarts of milk and water. Air blown downward through stack.

was but little difference between the top and bottom layers of water until the temperature dropped to near the point of maximum density of water. At 39.1° F. (3.9° C.) there was no difference between the bottom and top layers of water; below this temperature the bottom became the warmer, and the convection currents in the liquid were reversed.

The same general action took place in the quart bottle of milk; the readings, however, were reversed at 60° F. (15.6° C.), as indicated by the vertical dotted line from the point where curve 7 crosses the line of maximum density of water to the intersection of curve 5. Before this point was reached the top layers of milk were the hotter; afterwards the bottom ones showed the higher temperature. The maximum density of milk occurs just above the freezing point, which is about 31° F. (−0.6° C.); hence it might be expected that the top would remain the warmer above that temperature and that there would be no reversal in the readings of the thermocouples. This was not the case, however, in these experiments. There are several factors which may have influenced and probably did affect the cooling, among them being:

1. The placing of the upper couple above the cream line.
2. The rising of the cream to the top of the bottle.
3. Variation in the specific heat at different temperatures.
4. Increase in viscosity with decrease in temperature.
5. Increase in cohesion with lowering temperature.
6. The rapidity at which cooling took place.
7. Convection currents in milk only and not in the cream.
8. Separation of the constituents in the milk.
9. Relative areas of parts of bottle exposed to the cold air.
10. Relative positions of couples from top and bottom of bottles.

COST OF COOLING BY MEANS OF COLD OUTSIDE AIR.

To determine the cost of cooling by using cold outside air, the readings which appear below are given. These data were obtained from an experiment in which air at about 40° F. (4.4° C.) was blown down through the crates of bottles. The temperature curves are shown in figure 12.

Dry-bulb temperature	45° F. (7.2° C.).
Wet-bulb temperature	44. 6° F. (6.99° C.).
Difference	.4° F. (0. 23° C.).
Barometer	29. 85.
Weight of air per cubic foot	0.07837 pound.
Velocity head	0.40 of an inch of water.
Average temperature of outgoing air	58.1° F. (14.5° C.).
Average temperature of incoming air	39.6° F. (4.2° C.).
Cross-sectional area of pipe	1.07 square feet.
Average speed of fan	1,020 R. P. M.
Average volts	98.
Average ampere	20.
Total time of operation	148.5 minutes.

The velocity of air calculated from the Pitot-tube readings is $997\sqrt{\frac{.4}{.07837}}=2{,}253$ feet a minute, and the volume of air discharged each minute is $2{,}253\times 1.07=2{,}410$ cubic feet. The readings, however, were taken in the discharge pipe after the air had been heated by passing over the hot bottles; hence the volume of cold air supplied should be corrected in the ratio of the absolute temperatures of the air at the inlet and outlet of the box, or $\frac{2{,}410\times 499}{517}=2{,}326$ cubic feet of cold air supplied each minute.

The time of operating was 148.5 minutes to cool to approximately 45° F. Therefore the total amount of air supplied for cooling was $148.5\times 2{,}326=345{,}411$ cubic feet at an average temperature of 39.6° F. (4.2° C.), or a total weight of $345{,}411\times 0.07838=27{,}069$ pounds.

The heat required to raise the temperature of this amount of air and perform the work of expanding the air, which was furnished by the liquid, bottles, and crates inside the box, is $27{,}069\times 0.169(58.1-39.6+\frac{1}{778}\times 18(357{,}785-345{,}411))=84{,}919$ B. T. U. In other words, 34,919 B. T. U. is the amount of heat absorbed from the materials inside the box, and it is obvious that the heat given up by these materials should theoretically equal or balance the amount absorbed by the air.

Following are data and calculations of the amount of heat given up by the liquid, glassware, and crates:

Weight of water used in experiments	677 pounds.
Initial temperature of water	137.4° F. (58.55° C.).
Final temperature of water	45.7° F. (7.61° C.).
Difference	91.7 F. (50.94° C.).
Weight of glass	572 pounds.
Initial temperature of glass	137.4° F. (58.55° C.).
Final temperature of glass	45.7° F. (7.61° C.).
Difference	91.7° F. (50.94° C.).
Weight of wood in crates	189 pounds.
Initial temperature of wood	79.0° F. (26.11° C.).
Final temperature of wood	43.3° F. (6.28° C.).
Difference	35.7° F. (19.83° C.).
Weight of iron in crates	198 pounds.
Initial temperature of iron	79.0° F. (26.11° C.).
Final temperature of iron	43.3° F. (6.28° C.).
Difference	35.7° F. (19.83° C.).
Average temperature of air in room	70.0° F. (21.1° C.).
Average temperature of outgoing air	58.0° F. (14.4° C.).
B. T. U.[1] extracted from water, 677 (137.4−45.7)	=62, 080
B. T. U. extracted from glass, 572×0.1877 (137.4−45.7)	= 9, 848

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[1] Fahrenheit degrees were used in the calculations; hence results are in B. T. U.

B. T. U. extracted from wood, $198\times0.5\ (79.0-43.3)$ .... = 2,534
B. T. U. extracted from iron, $198\times0.113\ (79.0-43.3)$ .... = 799

75,261

B. T. U. through walls of box, $\frac{296\times4(70-58)2.47}{24}$ .... = −1,462

73,799

The foregoing figures indicate that 12 per cent more heat was taken out than the material gave up, which, of course, is impossible; hence it is believed that the Pitot-tube readings were wrong, as the weight and temperature of the material were carefully determined and are believed to be correct. On the other hand, if the anemometer readings of air velocities are taken and calculations made with them as a basis, the two sets of calculations balance within 2 per cent. In other words, 98 per cent of the heat given up in cooling the liquid, glassware, and crates is accounted for in the heat balance, showing that all our observations were practically correct. With this, then, as a basis, the total amount of refrigeration performed was $\frac{73,799}{288,000}=$ 0.26 ton, or at the rate of 0.106 ton an hour. The horsepower input to the motor $=\frac{98\times20}{746}=2.6$. The efficiency of the motor, however, was not determined, but in view of the fact that it was designed for a voltage of 120 and was operated at a voltage of only 98, its efficiency was necessarily low. Under the operating conditions, and assuming a cost of 6 cents a kilowatt hour for electric energy, the cost of power per ton of refrigeration was $1.11. When the air supply is colder, the time required to cool the milk is, of course, shorter; hence the cost of power is decreased. The over-all efficiency of a direct-connected blower set of this size and type when operated under normal service conditions should be about 40 per cent, but under our conditions it was only about 22 per cent; hence the cost of power for cooling in these experiments is considerably greater than it should be in a commercial plant. If the over-all efficiency of the blower set is assumed to be 40 per cent, then the total cost of electric energy, under the conditions mentioned above, and at a cost of 6 cents a kilowatt hour, would be only about 66 cents a ton of refrigeration.

As the blower set used in these experiments was operated very inefficiently, the cost of cooling is not typical of this method. The figures obtained do serve, however, to show that the cost of cooling by means of circulating cold outside air is very small. Of course, this can not be done throughout the year, but in a great many localities cooling may be accomplished by circulating cold outside air through the refrigerating rooms during several months of the year. In summer the air would have to be cooled artificially. This, however, is being done in a large number of milk plants which cool the air in a separate coil room and circulate it through the milk-storage room for the purpose of holding a low temperature in the room, the milk being cooled by running over some form of cooler before it is bottled and placed in the room.

It seems probable, from our results on a small experimental scale, that with outside air at a temperature of 40° F. (4.4° C.) or below, the process of cooling hot bottled milk can be successfully accomplished by forced circulation, No artificial refrigeration of the air is then necessary.

EFFECT OF SLOW COOLING ON THE BACTERIAL FLORA OF MILK AFTER PASTEURIZATION.

It is believed that any system of pasteurization in which the milk is not cooled immediately after heating will be looked upon with suspicion and will excite comment. It has always been supposed that immediate cooling was an indispensable part of the process of pasteurization (1) because sudden changes in temperature were believed to have a destructive effect on the bacterial cells and (2) because it has been supposed that bacteria left after pasteurization would immediately begin to grow unless the milk were cooled at once. It has been shown by Ayers and Johnson [1] that sudden cooling plays no part in the destruction of bacteria. One question, therefore, remains to be answered: How quickly must pasteurized milk be cooled in order to check bacterial growth?

From former studies of pasteurization it seemed apparent that the bacteria which survived heating were somewhat weakened or, at least, did not begin to grow, as might be expected. These observations naturally gave rise to the idea that pasteurized milk might be cooled directly in bottles by a forced-air circulation, provided the cooling period did not extend over more than a few hours.

In order to obtain data on this question 10 experiments were made, in which milk was first pasteurized and bottled hot in steamed bottles. In each experiment one of two bottles was then cooled to 45° F. (7.2° C.) within half an hour in ice water and held at that temperature in a refrigerator for 17½ hours, the other bottle being cooled slowly at room temperature for 4 hours and placed in a refrigerator at 45° F. (7.2° C.) for 14 hours. At the end of that time each bottle of milk was 18 hours old; one had been cooled slowly and had been at 45° F. (7.2° C.) for probably a very short time, because, although it had been in the refrigerator for 14 hours, the milk was warm when placed there and cooling in still air is a slow process. Both bottles after the 18-hour cooling period were allowed to stand for 6 hours at temperatures of from 75° to 85° F. (23.9° to 29.4° C.). The bacterial results are seen in Table I.

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[1] Ayers, S. Henry, and Johnson, W. T., jr. A study of the bacteria which survive pasteurization. Bul. 161, Bureau of Animal Industry. 1913.

TABLE I.—*Bacterial growth in milk during a quick and slow cooling to 45° F., followed by holding for 6 hours at warm temperatures (bacteria in 1 c. c.).*

	Sample No.									
	1	2	3	4	5	6	7	8	9	10
Raw milk	95,000	176,000	176,000	97,500	97,500	......	450,000	......	985,000	38,000
Milk cooled quickly:										
Directly after pasteurization	600	1,870	1,570	5,900	5,900	22,900	890	4,800	8,300	5,500
After 18 hours held at 45° F.	1,000	[1] 2,050	[1] 2,370	......	......	16,600	1,700	2,500	8,900	5,200
Sample then placed for 6 hours at 86° F	......	5,750	8,400	6,600	5,900	......	......	......	[2] 9,600	[2] 5,200
Milk cooled slowly:										
Directly after pasteurization	860	1,320	1,220	5,900	5,900	21,800	890	5,400	7,500	6,500
Cooled slowly at room temperature for 4 hours and placed for 14 hours in refrigerator at 45° F	500	1,180	5,520	......	......	12,300	2,200	715	9,800	5,200
Then placed for 6 hours at 86° F	......	5,800	6,100	3,700	3,700	......	......	......	[2] 8,900	[2] 5,300

[1] Held at 45° F. for 21 hours, in place of 18 hours.

[2] Held at 75° F., instead of 86° F.

As may be seen in Table I, bacterial counts were made on each bottle of raw milk directly after pasteurization, at the end of the 18-hour cooling period, and again after the milk had been at room temperature for six hours. The results obtained showed that there was no more increase in the pasteurized milk cooled slowly than in similar milk cooled within half an hour and held at low temperatures for 18 hours. Neither was there any difference in the bacterial numbers, even after milk cooled by both processes had been removed, after 18 hours' cooling, and allowed to stand for 6 hours.

The various counts from the 10 samples are averaged in Table II, in order to show more plainly the effect of the two systems of cooling on the bacterial numbers in milk.

TABLE II.—*Summary of results from Table I.*

Milk and stage of cooling process.	Average bacteria per c.c.
Cooled quickly:	
Directly after pasteurization	5,823
After 18 hours in refrigerator	5,040
Taken from refrigerator and held 6 hours at temperatures from 75° to 86° F	6,908
Cooled slowly:	
Directly after pasteurization	5,729
Cooled slowly at room temperature for 4 hours and held in refrigerator for 14 hours at 45° F	4,678
Taken from refrigerator and held for 6 hours at temperatures from 75° to 86° F	5,583
Raw milk	264,375

It will be seen in this table that the average bacterial counts of milk cooled slowly, made at different times, are even lower than those of milk cooled quickly. While this difference is possibly an experimental error, it is evident that bacterial growth in the pasteurized milk was not increased by the slow-cooling process.

We do not wish to convey the idea that pasteurized milk need not be cooled at all. The cooling of any milk is absolutely essential in order to restrain bacterial growth, and we wish to emphasize the fact that the process of cooling pasteurized milk slowly does not eliminate the cooling process, but simply makes use of a slower cooling process than is in use at present.

In order to show, respectively, the effect of cooling quickly, cooling slowly, and not cooling to low temperatures at all, three experiments were made. Milk was pasteurized in bulk, and three steamed and hot quart bottles were filled with hot milk. One bottle was cooled in ice water in half an hour to 50° F. (10° C.) and refrigerated at 45° F. (7.2° C.). Another bottle was cooled in a blast of air at room temperature for half hour, during which time the temperature dropped from 145° F. (62.8° C.) to about 100° F. (37.8° C.). The milk was then allowed to stand at a temperature of from 100° to 80° F. (37.8° to 26.7° C.) for five hours, after which it was placed in a refrigerator at 45° F. (7.2° C.), where it cooled slowly in still air. The other bottle was cooled for half an hour in an air blast at room temperature and allowed to remain at a temperature of about 75° F. (23.9° C.) throughout the experiment. The results of these experiments, in which bacterial counts were made at different stages of the cooling process, are given in Table III.

TABLE III.—*Effect of different methods of cooling on the bacterial content of pasteurized milk (bacteria in 1 c. c. of milk.)*

	Sample No.		
	1	2	3
Raw milk	9,050,000		11,900,000
Cooled quickly:			
Directly after pasteurization	6,450	2,110	8,500
Held at 45° F. for 22 hours	5,050	1,720	28,400
Held at 75° F. for 6 hours	4,800	2,340	76,500
Held at 75° F. for 24 hours	1,370,000	885,000	
Cooled slowly:			
Directly after pasteurization	7,150	2,580	11,900
Held at 80° to 100° F. for 5 hours	6,100	1,600	29,000
Held at 45° F. for 17 hours	6,200	2,400	192,000
Held at 75° F. for 6 hours	9,600	2,740	348,000
Held at 75° F. for 24 hours	2,760,000	850,000	
Allowed to cool naturally in air 75° F.:			
Directly after pasteurization	4,950	2,180	8,500
Held at 75° F. for 5 hours	6,850	2,890	25,000
Held at 75° F. for 22 hours	700,000	2,420,000	83,400,000
Held at 75° F. for 28 hours	2,750,000	13,400,000	269,000,000
Held at 75° F. for total of 66 hours	460,800,000		

A study of the table shows that there was no increased bacterial growth in experiments 1 and 2 caused by holding the pasteurized milk for five hours after bottling hot, even though the temperature during that period ranged from 100° to 80° F. (37.8° to 26.7° C.), which is the most favorable temperature for bacterial development. In experiment 3 there was an increased growth compared with that in the milk cooled quickly. It must be remembered that these experiments represent extreme conditions in slow cooling, but the fact is apparent that the cooling process should not extend over five hours. The effect of not cooling milk to low temperatures is plainly shown in the table by a comparison of the bacterial counts with those of milk cooled both quickly and slowly.

The results which have been thus far presented on the bacteriological effect of slow cooling were obtained from observations of bottles held under extreme laboratory conditions. We realize that laboratory experiments do not always apply to commercial conditions, so the results shown in Table IV were determined from experiments conducted on a 30-crate basis. Two quart bottles of milk were examined in each experiment. The crates were stacked five high, and one bottle was placed in the lower crate and the other in the upper one. The cooling was conducted in the usual way, 30 crates being stacked in the cooling box, as has been described. This table shows the bacterial content of the raw milk, the bacterial content of the hot pasteurized milk bottle immediately after pasteurization for 30 minutes at 145° F. (62.8° C.), and also the bacterial content after the bottles had been cooled by forced-air draft.

TABLE IV.—*Effect of slow cooling on bacterial content of pasteurized milk (milk cooled on a small commercial scale).*

Experiment No.	Bottle No.	Bacteria per cubic centimeter.			Length of cooling period.
		Raw milk.	After pasteurization for 30 minutes at 145° F.	After cooling by forced-air circulation.	
					Minutes.[1]
1	1	490,000	5,400	3,850	155
	2		7,100	2,850	
2	1	128,000	5,000	3,900	150
	2		4,400	4,400	
3	1	12,800,000	155,000	18,900	148
	2		156,000	13,900	
4	1	140,800,000	525,000	32,000	127
	2		555,000	50,500	
5	1	7,400,000	132,000	95,500	93
	2		161,000	78,500	

[1] Milk cooled to about 75° F.; in all the other experiments the milk was cooled to below 50° F.

In experiment 1 the milk was cooled during a period of 155 minutes to about 75° F. (23.9° C.) only, as the outside air was warm, but as will be seen from the results the bacterial count was even lower after cooling than before. In the other four experiments the milk was cooled to below 50° F. (10° C.), and the length of the cooling period varied from 93 to 150 minutes. It is interesting to note that when the bacterial count in the raw milk was high, there was a marked reduction in the number of bacteria during the process of cooling by forced-air circulation. When the bacterial content of the raw milk was low, the reduction caused by slow cooling was not so marked, although the bacterial count was usually less.

From the foregoing experiments, conducted on a laboratory and also on a small commercial scale, it seems evident that there is no bacterial increase in pasteurized milk which is cooled slowly; on the contrary, there is often a decrease, especially when there are large numbers of bacteria in the milk before pasteurizing.

These results are of particular value, for they indicate that it is possible to cool hot pasteurized milk slowly by means of forced-air circulation. From the results of our experiments we believe this is possible without any bacterial increase in the milk, provided the cooling to 50° F. (10° C.) does not require a longer period than five hours. This period of time should not be exceeded. It should be remembered that even if a period of three hours is required to cool milk from 145° F. (62.8° C.) to 50° F. (10° C.), the temperature is within the growing range of bacteria for only a portion of that period. With the process of cooling by forced-air circulation on a commercial scale milk can be cooled to 50° F. (10° C.) within three hours, which is well within the 5-hour limit, and in order to have a wide margin of safety we recommend that hot-bottled pasteurized milk be cooled within three hours after it is bottled.

We wish to emphasize the fact that the bacteriological results which have been discussed apply only to the slow cooling of hot pasteurized milk during the process described in this bulletin. Pasteurized or raw milk must be held, after the cooling process, at low temperatures in order to check bacterial development.

EFFECT OF THE PROCESS ON THE CREAM LINE AND FLAVOR OF MILK.

In the consideration of the process of bottling hot pasteurized milk followed by slow cooling, it is of practical importance to know what effect such a process will have on the cream line and flavor of milk. Several laboratory experiments were first made to determine this matter. Milk was pasteurized, and hot 500 c. c. graduated cylinders were filled with hot milk up to the 500 c. c. mark. Together with the cylinder of hot pasteurized milk one cylinder was filled with raw milk and one with pasteurized milk which had been cooled to 50° F. (10° C.) in 15 seconds by running through a coil immersed in brine. The method of cooling the hot-bottled pasteurized milk was varied considerably, as may be seen in Table V. After holding the milk for 24 hours at 45° F. (7.2° C.) the numbers of cubic centimeters of cream were read off directly from the graduations on the cylinder. This method, of course, gave a very reliable means of determining the effect that heating and cooling had on the cream line; in fact, it was too accurate, since the marked differences in the cream line seen in the cylinders were not apparent in the bottled milk.

TABLE V.—*Laboratory cream-line experiments showing comparison of raw milk and milk pasteurized at 145° F. for 30 minutes followed by various methods of cooling.*

Experiment No.	Milk and process.	Cream in 500 c. c. cylinder after 24 hours' refrigeration at 45° F.
		C. c.
1	Raw	64.5
	Pasteurized:	
	Cooled quickly in 15 seconds to 50° F	64.5
	Cooled slowly in air blast for 45 minutes	65.0
	Held above 105° F. for three hours and cooled in ice water	64.5
2	Raw	65.0
	Pasteurized:	
	Cooled in 15 seconds to 50° F	62.5
	Cooled slowly in air blast for 1½ hours	52.5
	Held above 100° F. for 1½ hours	52.5
3	Raw milk lost	
	Pasteurized:	
	Cooled in 15 seconds to 50° F	83
	Cooled slowly for 30 minutes in air blast, then cooled quickly in brine	85
	Held above 100° F. for 3 hours, then cooled quickly in brine	90
4	Raw milk lost	
	Pasteurized:	
	Cooled in 15 seconds to 50° F	75
	Cooled slowly in air blast for 2½ hours, then cooled in ice water	69
	Held above 100° F. for 2½ hours and cooled in ice water	75
5	Raw	80
	Pasteurized:	
	Cooled in 15 seconds to 50° F	68
	Cooled slowly in air blast for 2 hours	55
	After cooling in air blast for 2 hours the milk was cooled quickly in brine to 50° F.	62
	Held above 100° F. for 5 hours	55
	After holding above 100° F. for 5 hours the milk was cooled quickly in brine to 50° F.	62

A study of the results shown in the table above indicates that cream-line formation is a variable factor. Sometimes it was reduced by pasteurization, even when the milk was cooled to low temperatures within 15 seconds, and at other times there was no difference. In some experiments the cream line was slightly less on milk cooled slowly.

These laboratory experiments do not exactly duplicate conditions of air cooling on a commercial scale, for in no case was the hot pasteurized milk cooled to 50° F. (10° C.) within three hours, as it was in our later experiments. Throughout our experiments on a small commercial scale, when the milk was cooled to that temperature within the time named no apparent reduction of the cream layer was observed, and the cream line was always distinct. When milk stood at temperatures above 80° F. (26.7° C.) for several hours without agitation, some of the melted butterfat rose to the top of the bottle and on cooling formed a small lump of butter. This was observed, however, when the cooling process was begun immediately after bottling, even though the cooling was gradual.

As to the effect of the process on the flavor of the milk, it may be said that there was no more noticeable flavor than is the case with milk pasteurized and cooled rapidly, except when the milk was held above 100° F. (37.8° C.) for several hours. This was the case in several of our experiments, and in these a slightly more pronounced cooked taste was noticeable in the milk. In this connection we wish to call attention to the fact that these results hold good only for milk pasteurized at 145° F. (62.8° C.) and are based on results obtained experimentally on a small scale. They can not be applied where higher temperatures might be used, as in such cases it is possible that different results may be obtained.

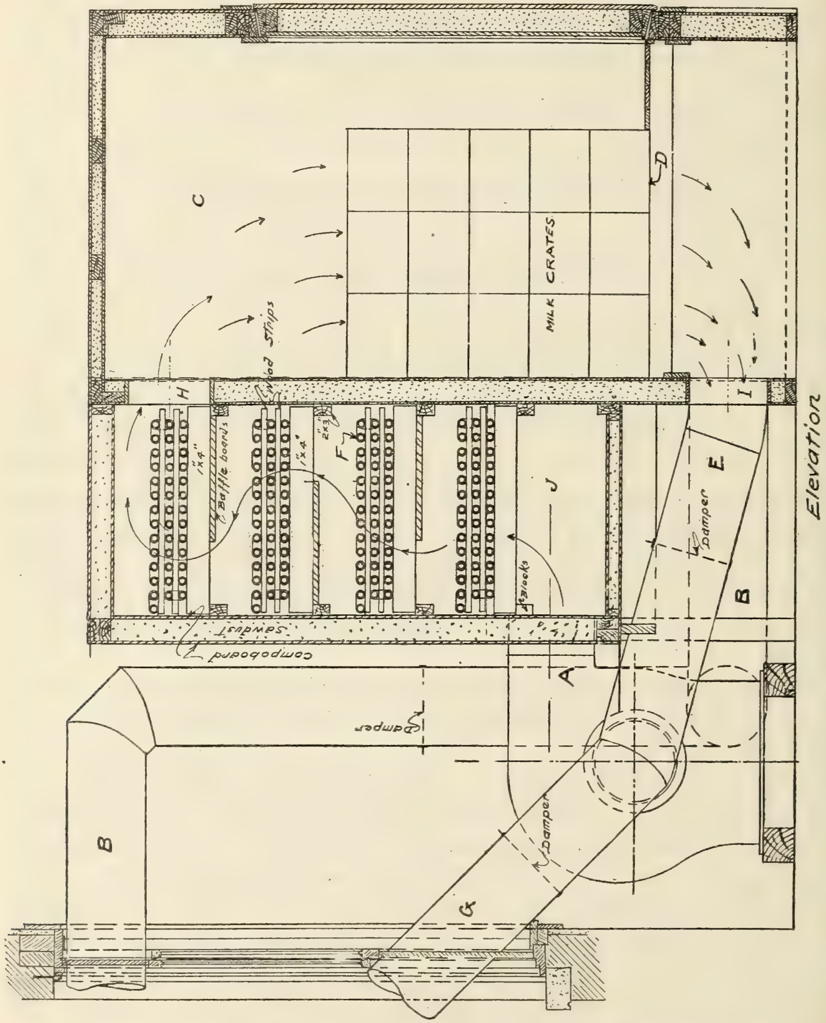

FIG. 17.—General arrangement of heating apparatus.

EXPERIMENTS IN HEATING BOTTLED MILK BY FORCED AIR.

The experimental apparatus used for heating the milk in the bottle by means of circulated hot air is shown in figure 17. It is the same general arrangement that was used for the cooling experiments except the addition of the bunker and heating coils. The crates were stacked in the box as shown, and the air was forced by the fan from the heating-coil bunker into the top of the box, down through the stack of crates, and out at the bottom. The floor of the box was made practically air-tight around the crates, so that the hot air necessarily had to flow through the crates and around the bottles in its passage from the box.

In figure 17 it will be noted that the galvanized piping for air was so arranged that by manipulating dampers a closed hot-air circuit would be maintained for heating, or cold air from the outside could be admitted to the box for the purpose of cooling. By closing the dampers in inlet pipe G and outlet pipe B and opening the damper in pipe E a closed hot-air circuit would be maintained in which the fan A would draw the hot air from the bottom of the box and force it upward around the heating coils and into the top of the box through the opening H, thence downward through the crates.

After heating the liquid to the desired point, the steam supply was cut off, the dampers were reversed, and cold outside air admitted to the box for cooling; that is, the dampers in pipes G and B were opened, and the one in pipe E closed. Then cold air from the outside was drawn in by the fan A, forced up through the heating coils and into the box through the opening H, thence downward through the crates, and outside through the pipe B. The heating coils were so arranged that the number of coils could be varied, thus making it possible to regulate the amount of heat in the box. The steam pressure and the amount of condensed steam from the coils were recorded during the experiments.

RESULTS OF HEATING FROM BOTTOM UPWARD.

Before the equipment was arranged as shown in figure 17, the heating coils were placed in the bottom of the box, under the platform, and the air was forced by the fan around the coils and upward through the stack of crates, leaving the box near the top. After the liquid was heated to the desired point, cold air for cooling was blown downward through the crates. The results obtained under these conditions are shown by the curves in figure 18. It will be seen that there was a wide variation in the temperatures of bottles at different parts of the stack.

After heating there was an average difference of 16° F. (8.9° C.) between the top and bottom quarts of milk, and a maximum difference of about 30° F. (16.7° C.). This variation in temperature is considered too great for satisfactory pasteurization, as certain bottles will be overheated while others will not be heated to the required point; furthermore, there is a variation in temperature of from 10°

to 15° F. (5.6° to 8.3° C.) between the top and bottom portions of milk contained in the same bottle. This is shown graphically in figure 19, the curves in which were plotted from data obtained in the experiment shown in figure 18. The distances of the curves above the zero line are considered as positive, and those below as negative. The points where the curves cross the zero line indicate equal temperatures at top and bottom of the bottle; hence the convective currents cease at these points. Above the zero line the topmost layers were the hottest, and below it the bottom ones were the hottest. It is of course very important that the milk be heated uniformly throughout the stack as well as in individual bottles; therefore it is believed that this method of heating will not give the desired results.

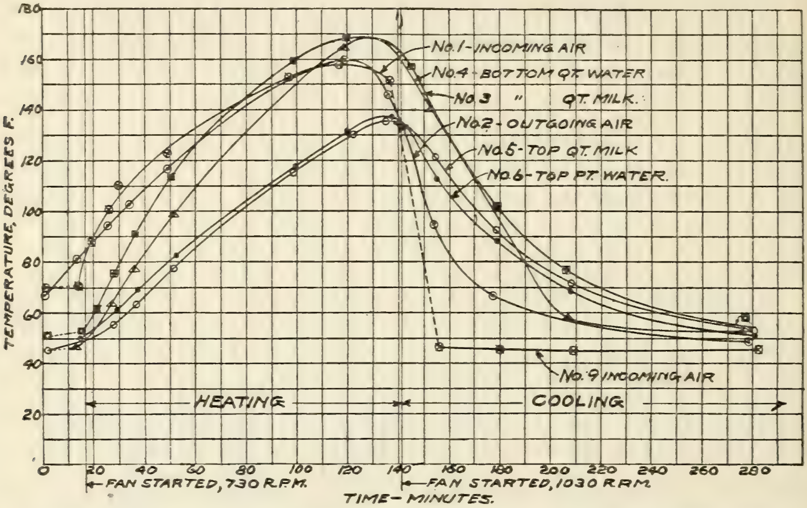

FIG. 18.—Heating and cooling by forced air.—Variation in temperature of bottles at different positions in stack when heating and cooling. Hot air in at bottom when heating and cold air in at top when cooling.

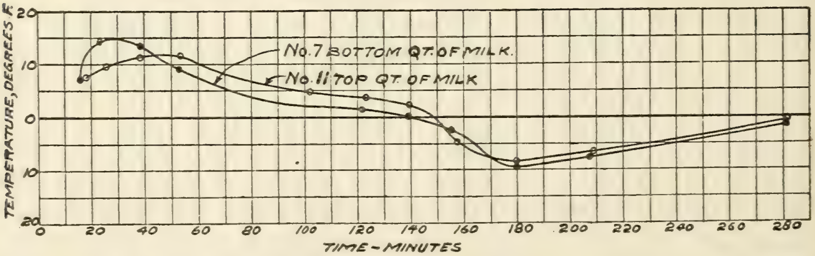

FIG. 19.—Heating by forced air.—Variation in temperature between top and bottom layers of milk in same bottle. Same experiment as in fig. 18.

RESULTS OF HEATING FROM TOP DOWNWARD.

After making several experiments with the heating coils in the bottom of the box, all of which gave unsatisfactory results, the arrangement of apparatus shown in figure 17 was used. With this arrangement the air was blown over steam coils and down through the crates, leaving the box near the bottom. The results are shown by means of curves in figure 20. In this case the crates were stacked five high, the pint bottles in the three lower crates, and the quarts in the two upper ones. By placing the quart bottles on top they came first into contact with the hottest air and naturally would be heated more quickly than the pint bottles at the bottom. There was still a wide difference in temperature, however, between the upper and lower tiers of bottles and also in the temperature of the top and bottom layers in the same bottle, where a maximum temperature difference of 82° F. (45.5° C.) was observed. It was therefore decided that neither of these methods is commercially practicable when the milk is contained in bottles.

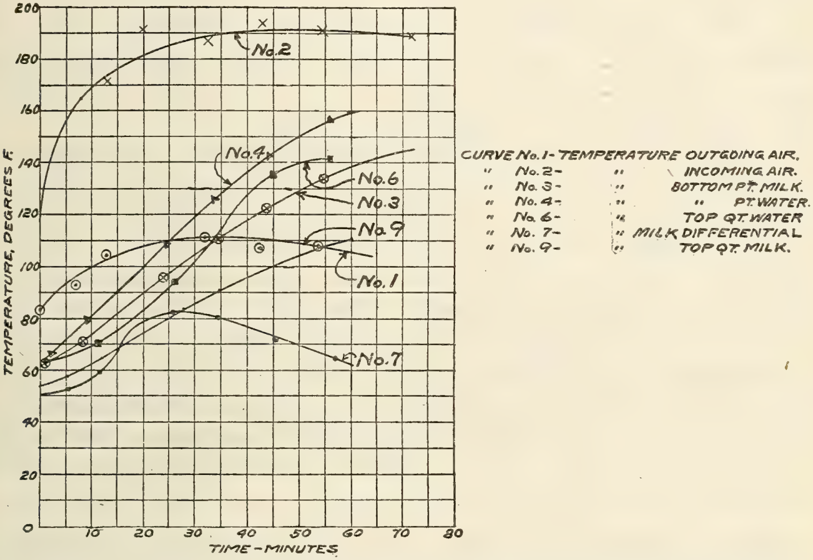

FIG. 20.—Heating by forced air.—Variation in temperature of bottles at different positions in stack. Hot air blown downward through crates.

GENERAL SUMMARY.

1. In these experiments bottles of water generally were used in place of milk, as it was found that there is very little difference in the relative rate of cooling milk and water. When quart bottles of milk and of water were cooled by forced-air circulation from 148° to 45° F. (64.4° to 7.2° C.), the milk cooled more slowly, but the maximum difference was about 2° F. (1.1° C.). On account of this small variation it was considered advisable to use water, as it was more easily obtained and handled. Bottles of milk, however, were distributed throughout the crates for bacteriological studies as well as for temperature readings.

2. A bottle of hot milk will cool about one-third faster in circulated air than in still air at the same temperature. This is also true of hot milk in 10-gallon cans. The time required to cool through a given range, other things being equal, depends upon the size of the containing vessel, and it is believed that in commercial practice quart bottles are about the largest-sized containers which should be used with this method. Cooling by natural circulation is too slow for satisfactory application on a commercial scale.

3. The cooling experiments were operated on a basis of 30 crates, stacked in 6 piles, each 5 crates high. When cold air was forced up through the crates, there was a wide variation in the temperature in the same sized bottles in different positions in the stack, as well as in quart and in pint bottles in the same position. This variation was too great for satisfactory operation on a commercial scale.

4. When the direction of the cooling air was reversed every 15 minutes during the cooling period, first up then down through the crates, the variation in the temperature of the bottles was reduced, but the cooling was not entirely satisfactory.

5. When air was forced down through the stacks of crates the cooling process was much more effective. The maximum difference in temperature in any of the bottles was about 4.5° F. (2.5° C.), and the average difference only approximately 2.5° F. (1.4° C.) when the bottles were all at the same initial temperature at the beginning of the cooling period. There was a difference of only 2° F. (1.1° C.) between the average and the maximum variation in temperature of different bottles, showing that the cooling was practically uniform. With air at 40° F. (4.4° C.) forced down through the crates at the rate of approximately 2,500 feet a minute, the bottles were cooled from about 140° F. (60° C.) to 50° F. (10° C.) in about two hours. With air at 30° F. (−1.1° C.), and at the rate of about 1,700 feet a minute, the bottles were cooled through the same range of temperature in approximately 1 hour and 30 minutes, and when it was at 20° F. (−6.6° C.) and forced down through the crates at the last-mentioned rate, the bottles were cooled from about 140° F. (60° C.) to about 50° F. (10° C.) in about 1 hour and 20 minutes.

6. There was a wide variation in temperature between the top and the bottom of the same bottle during the cooling period when air was forced up through the crates; this variation was practically eliminated when air was forced downward through them.

7. Cost of cooling by forced-air circulation, when the outside air temperature is 40° F. (4.4° C.) or lower, is materially less than that of the usual methods of refrigeration.

8. Bacteriological studies indicate that if milk is cooled from 145° F. (62.8° C.) to 50° F. (10° C.) within five hours after pasteurizing, no more bacterial increase will take place during the slow cooling

than if the milk were cooled immediately to the same temperature. In fact, in our experiments, on a 30-crate basis, there was a marked reduction in the bacterial numbers during the cooling period, especially when the raw milk contained large numbers of bacteria before pasteurization. From our experiments it seems that pasteurized milk can be cooled, on a commercial scale, from 145° F. (62.8° C.) to 50° F. (10° C.) by means of forced-air circulation within three hours; consequently the process can be completed well within the 5-hour limit. In order to have a wide margin of safety and to obtain the best results, we recommend that the cooling process be started immediately after the hot pasteurized milk is bottled and that it be completed within three hours.

The cooling of milk is absolutely essential in order to restrain bacterial growth, and we wish to emphasize the fact that the process of cooling slowly does not eliminate the cooling process, but simply makes use of a slower-cooling process than is in use at the present time.

9. So far as our laboratory experiments on a 30-crate basis indicate, slow cooling of hot-bottled pasteurized milk has no appreciably detrimental effect on the cream line and the flavor of the milk. This is true for periods of cooling of not more than three hours. It is, of course, possible that different results may be obtained on a large commercial scale.

10. On account of the uneven heating of pint and quart bottles in similar positions, and the same-sized bottles in different position in the stacks, attempts to heat milk in bottles by means of forced-air circulation were not successful. It was found impossible to heat the bottles to the pasteurizing temperature of 145° F. (62.8 C.) without overheating some of them.

CONCLUSION.

Our results indicate that it is commercially practicable to cool hot pasteurized milk in containers not larger than quart bottles by forcing cold air downward over them when the air is at a temperature of 40° F. (4.4° C.) or lower.

On account of overheating portions of the milk, the process of pasteurizing milk in bottles by forcing hot air over them seems commercially impracticable.

This bulletin contains experimental data on the method of cooling hot-bottled milk by forced-air circulation which we believe will be of assistance in the practical application of this method of cooling. When the temperature of the outside air is 40° F. (4.4° C.) or lower, it may be used for this purpose, but when it is higher than that it must be cooled by mechanical refrigeration. It is possible to use a combination of outside air and refrigerated air; that is, outside air at a temperature of, say, 60° or even 70° F. (15.5° to 21.1° C.) may be used to cool the milk partly, the remainder of the cooling being done by mechanical refrigeration. It should be noted, however, that in cooling milk on a large scale by this method some unforeseen difficulties may arise which we did not encounter in our experiments.

This process of cooling by forced-air circulation, if commercially practicable, could be applied to advantage for cooling hot-bottled pasteurized milk. Briefly stated, the complete pasteurizing and cooling process could then be as follows:

Milk could be pasteurized by the ordinary holder system at 145° F. for 30 minutes. It could then be bottled hot in special oversized milk bottles of the ordinary type and capped with ordinary sterile caps. Before being filled, the bottles could be steamed for two minutes by running the crates inverted on a conveyer over steam jets; the bottles would then go through the bottling machine in a hot condition and would be practically sterile. The crates of hot-bottled pasteurized milk could then be cooled by stacking in a refrigerator room and blowing cold air through the crates. In the cold season outside air could be used for cooling, and in the warm season refrigerated air could be circulated through the crates.

This process could be modified in two ways: The hot milk could be held in the bottles at 145° F. instead of in a tank, and the crates of hot pasteurized milk could be cooled by spraying with cold water instead of air.

From a sanitary point of view the important advantage of the process of bottling hot pasteurized milk in hot bottles lies in the fact that bottle infection is eliminated, and if the bottles of hot milk can be cooled successfully by forced-air circulation, the process of pasteurization would be raised to its highest state of efficiency by relatively simple methods.

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